AN EXPERIMENTAL INVESTIGATION OF SKIN FRICTION DRAG REDUCTION

Grant Number NSG 1049

NEW YORK UNIVERSITY
DIVISION OF APPLIED SCIENCE
AEROSPACE AND ENERGETICS LABORATORY
MERRICK AND STEWART AVENUES
WESTBURY, L.I., NEW YORK 11590

PROGRESS REPORT

April 1, 1974 through September 30, 1974

OCTOBER 1, 1974

I. INTRODUCTION

This research is directed toward the experimental evaluation of the effect of tangential slot injection on reducing the surface skin friction of transonic flow having zero pressure gradient. In order to eliminate the influence of stream turbulence in the mixing, solid wall and slot injection technique will be used here. The experimental setups and test conditions are presented in this report.

II. WIND TUNNEL SETUP

Three wind tunnel setups will be constructed to perform the experiments with different slot heights for single and multiple slot injections. Schematics of the wind tunnel setup are presented in the following:

1) Single Slot Injection with Slot Height S = 0.25 IN, Fig. 1

In addition to the measurements of the local skin friction, boundary layer profiles at the slot location and downstream of the injection slot, will be measured by traversing the boundary layer with static pressure, total pressure, and total temperature probes. Turbulent fluctuations will also be measured with a hot wire. From the boundary layer computation for a Mach 0.8 free stream, ratio of the boundary layer thickness at the slot location to the slot height is found to be approximately 1.50.

2) Single Slot Injection with Slot Height S = 0.125 IN., Fig. 2

The local skin friction with different slot injection will be measured in this wind tunnel configuration. A ratio of approximately 1.70 between

the theoretical boundary layer thickness at the slot location and slot height has been found.

3) Two Slot Injection with Slot Height S = 0.125 IN., Fig. 3

For this test arrangement, the local boundary layer thickness at the second injection slot will be changed by the first slot injection such that the effect of the boundary layer thickness external to the second injection slot on the local skin friction downstream of the injection slot can be investigated. Besides the local skin friction measurements, boundary layer profiles at the second slot will be measured with several first slot injection mass flow rates.

III. ESTIMATION OF THE LOCAL SKIN FRICTION

It has been found from high speed slot injection that tangential slot injection significantly decreases the local skin friction downstream of the injection slot. Thus, the maximum values of the local skin friction can be estimated from the boundary layer theory without injection effect. This estimation is required in the determination of the calibration of the local skin friction gauge.

Results of the local skin friction factor based on turbulent boundary layer theory for the case of zero injection mass flow rate are shown in Fig. 4. Calibrations of the local skin friction gauge in ranges of 0.1 gram/cm^2, 1.0 gram/cm^2, and 10.0 gram/cm^2 are shown in Figs. 5, 6, and 7. Comparisons among these data indicate that the skin friction gauge fits the requirement of present experiment.

IV. CALIBRATION OF THE VENTURI TUBE

From the calibration curve of the existing ¼ inch venturi tube and the proposed test conditions of $T_{o_\infty} = 530^{o}R$, $M_\infty = 0.8$, and $p_\infty = 14.7$ psia, the values of the injection mass flow rate λ, velocity ratio u_j/u_∞, and the venturi supply pressure with S = 0.125 IN. are listed in Table 1. Similar ranges of the injection mass flow rate will be used for the case of S = 0.25 IN.

V. TEST CONDITIONS AND PROCEDURES

For all the tests, the tunnel stagnation conditions will be kept at $p_{o_\infty} = 20$ psia and $T_{o_\infty} = 800^{o}R$. Mach 0.8 transonic flow will be established by choking the tunnel downstream of the test section. The injection mass flow rate will be adjusted between 0 amd 0.30 with venturi tubes. Present tests will follow the order of the wind tunnel setup and the following measurements will be performed:

1) Single Slot Injection with S = 0.25 IN. Measurements Include:
   a) Surface pressure distribution
   b) Local skin friction
   c) Boundary layer profiles of static pressure, total pressure and total temperature
   d) Turbulent fluctuations

2) Single Slot Injection with S = 0.125 IN. Measurements Include:
   a) Surface pressure distribution
   b) Local skin friction

3) Multiple Slot Injection with S = 0.125 IN. Measurements Include:

a) Surface pressure distribution

b) Local skin friction

c) Boundary layer profiles at the beginning of the second slot

Local skin frictions at 20 locations over a distance of 200 S downstream of the injection slot will be measured for each test setup. However, boundary layer profiles at fewer locations will be measured only.

VI. DATA REDUCTION

The calibration curve of the skin friction gauge will be used to find the experimental local skin friction factor from the measured voltage output. The boundary layer velocity profiles will be obtained from the profiles of static pressure, total pressure, and total temperature. The profile measurements will also be transformed into corresponding incompressible flow and compared with the Law of the Wall. Additional information of the local skin friction factor will be found from the profile measurements and compared with the results of direct measurements. Pressure taps, scanivalves, and pressure transducers will be used to measure the wall surface pressure.

VIII. REMARKS

Designs of the wind tunnel setup, test section, and the instrumentation plate, calibrations of the venturi tube, estimations of the local skin friction factor have been accomplished. The unique feature of the present

tunnel design is that only one test section is required for the present experiments of different slot dimension. The slot height can be changed by interchanging the upstream part of the slot configuration. This test section can slso be used to measure the boundary layer skin friction without the effect of upstream injection slot, Fig. 8. Since the skin friction gauge has a 6 inch radius, the test section is made to also have a radius of 6 inches for all the skin friction measurements.

Currently, we have been constructing the parts of the test section. It is expected that the tests of the single slot injection with S = 0.25 IN., will start in the near future.

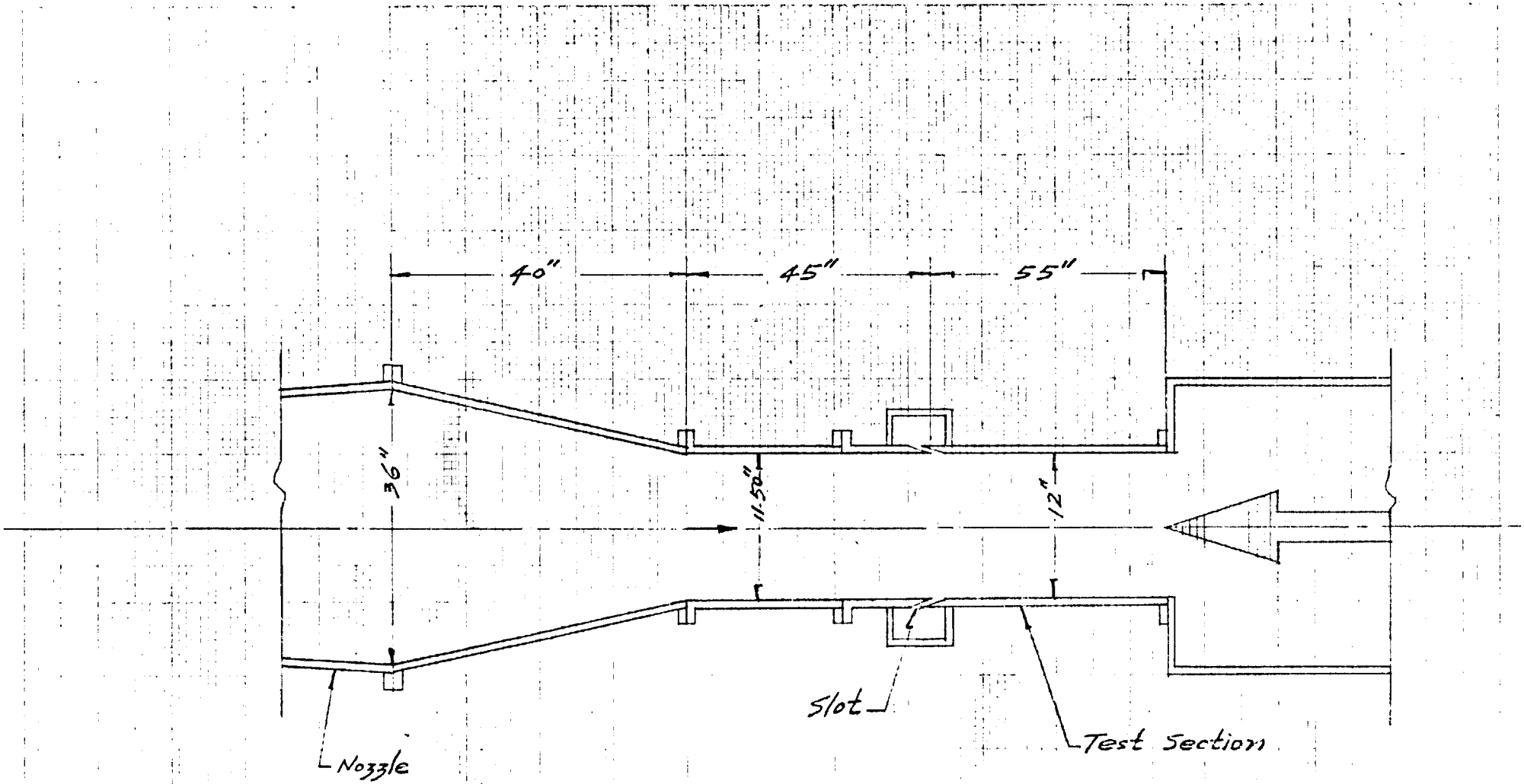

Fig. 1 Schematic of Wind Tunnel set-up for Single Slot Injection
S = 0.25 IN.

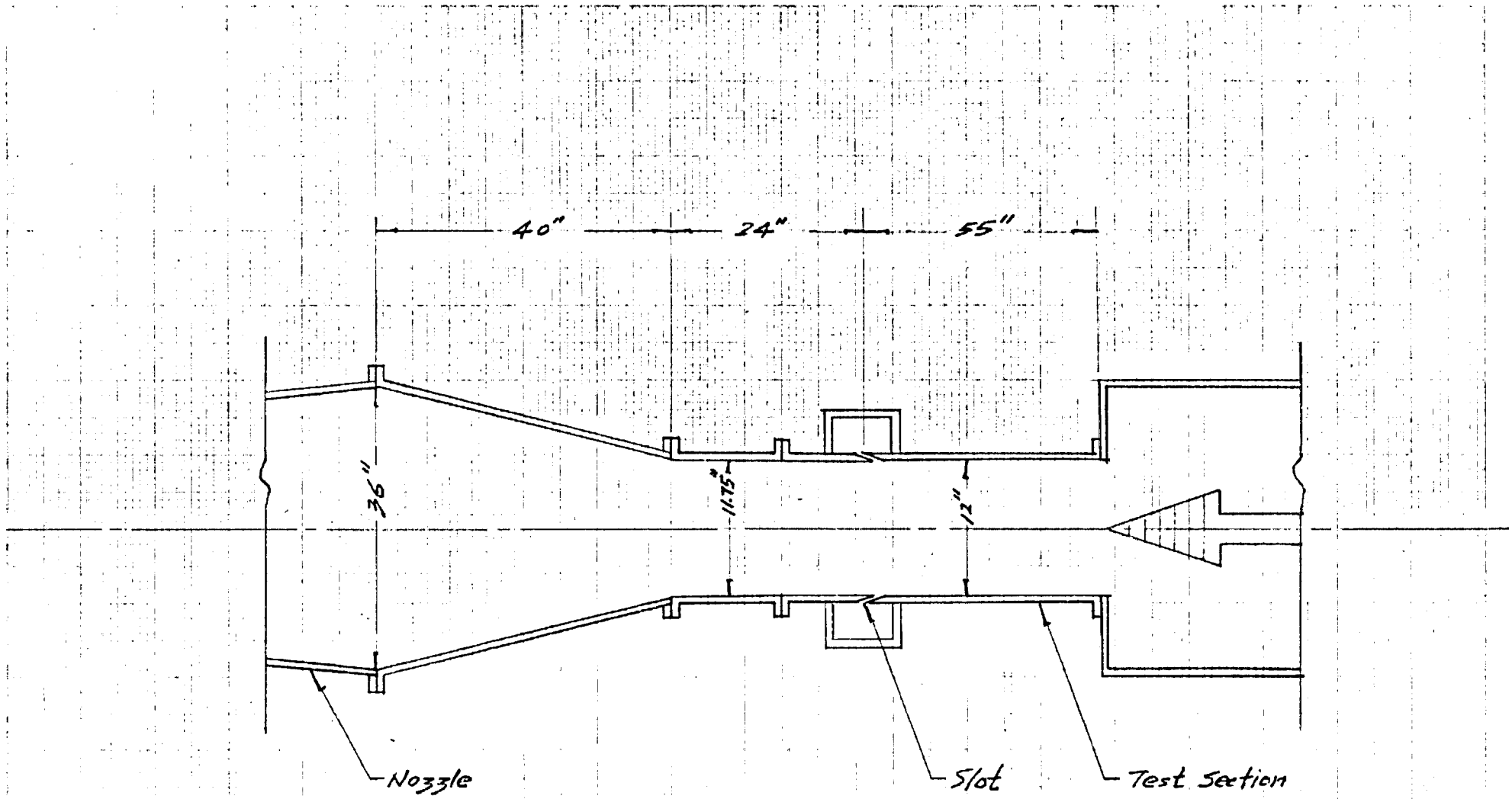

Fig. 2 Schematic of Wind Tunnel Setup for Single Slot Injection
S = 0.125 IN.

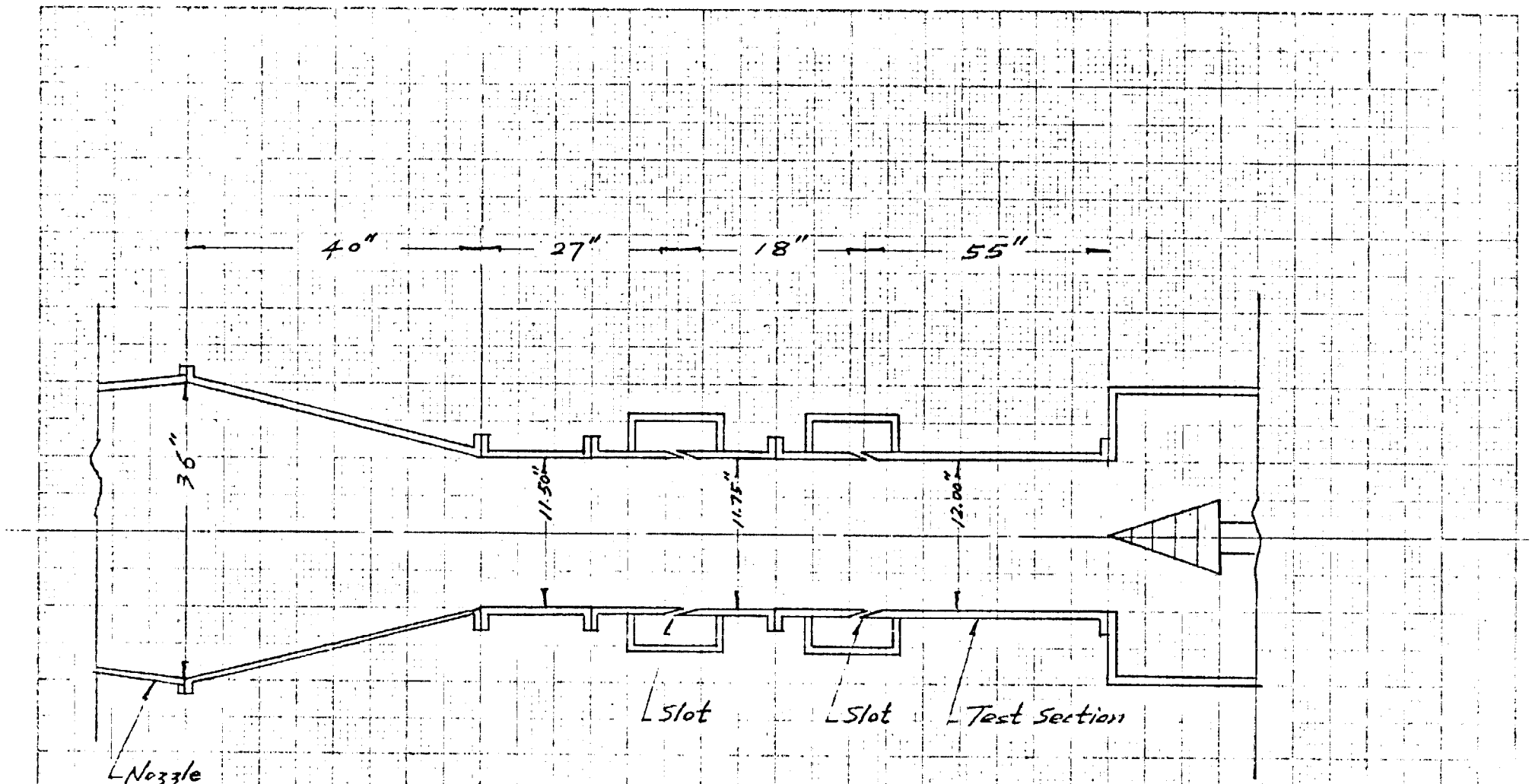

Fig. 3 Schematic of Wind Tunnel Setup for Multiple Slot Injection

S = 0.125 IN.

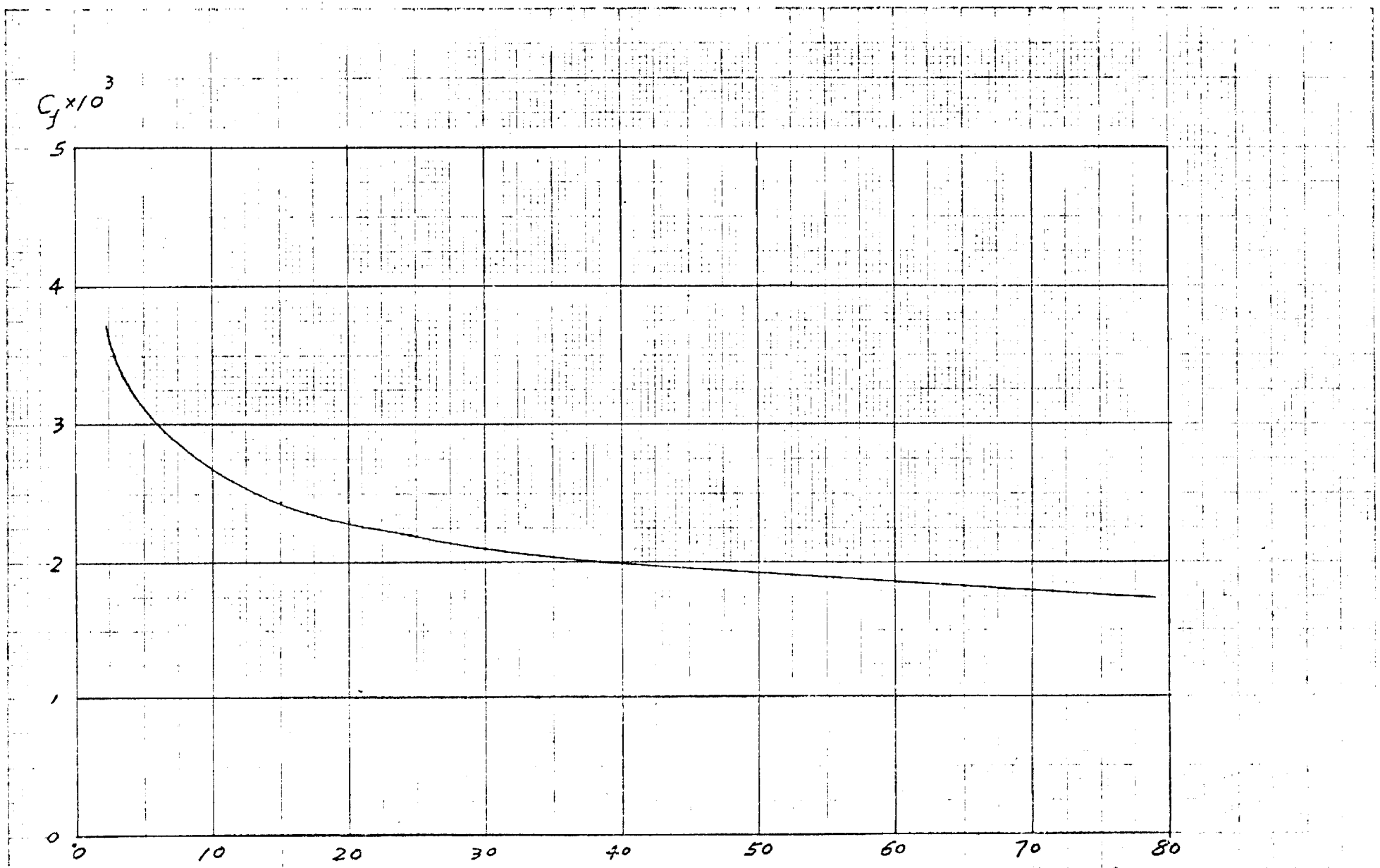

Fig. 4 Distribution of Local Skin Friction for $\lambda = 0.0$

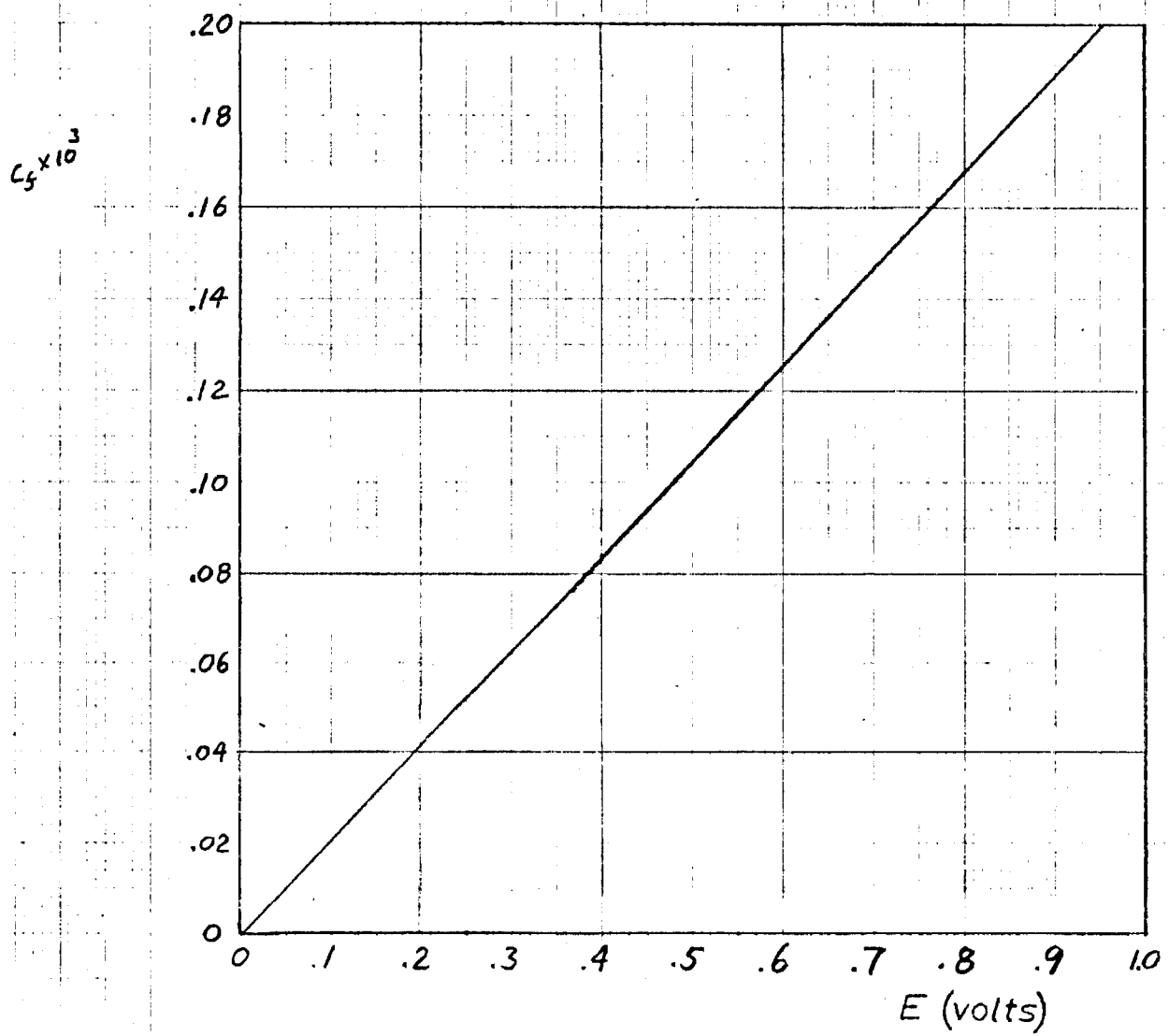

Fig. 5 CALIBRATION OF SKIN FRICTION GAUGE, range 0.1 gram/cm^2

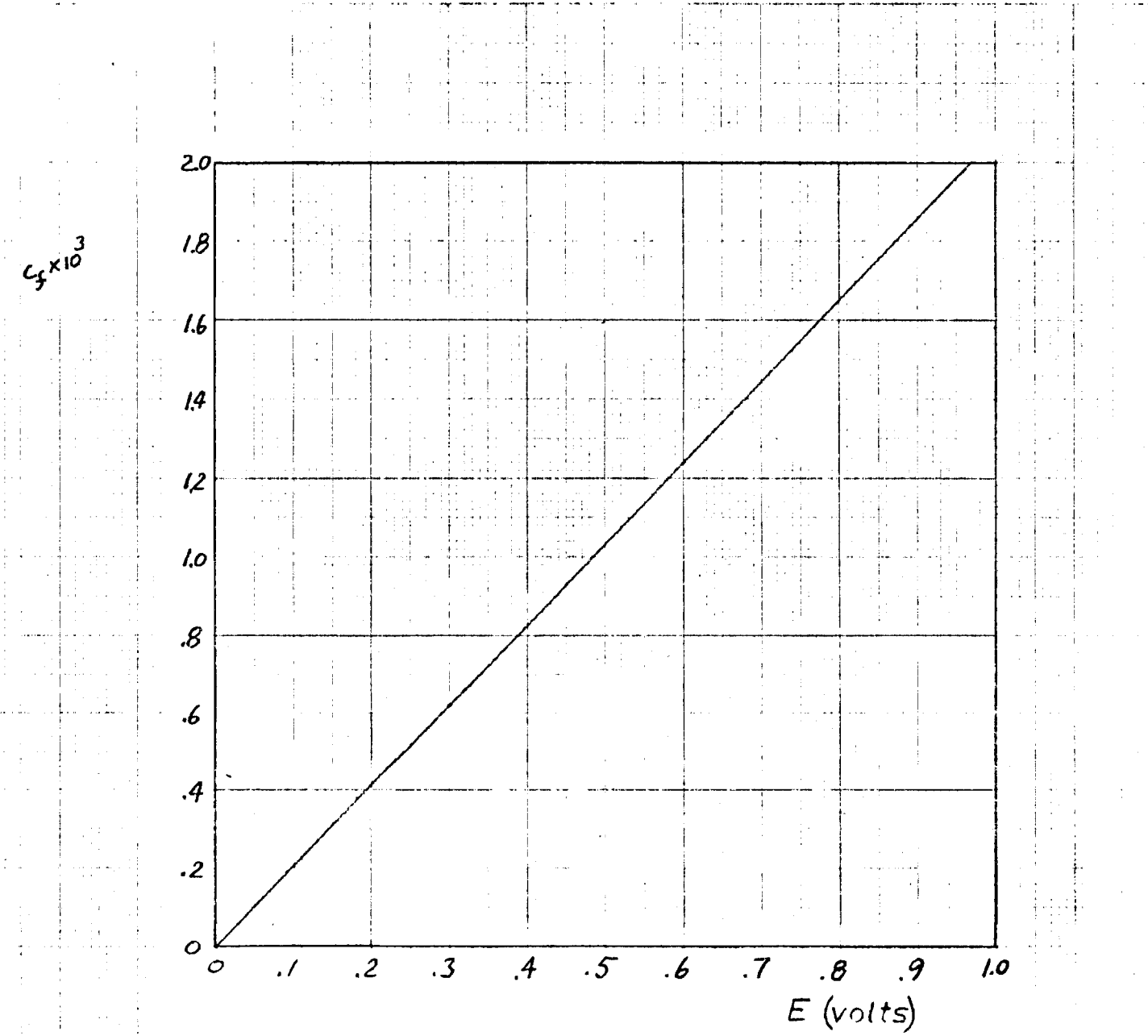

Fig. 6 CALIBRATION OF SKIN FRICTION GAUGE, range 1.0 gram/cm^2

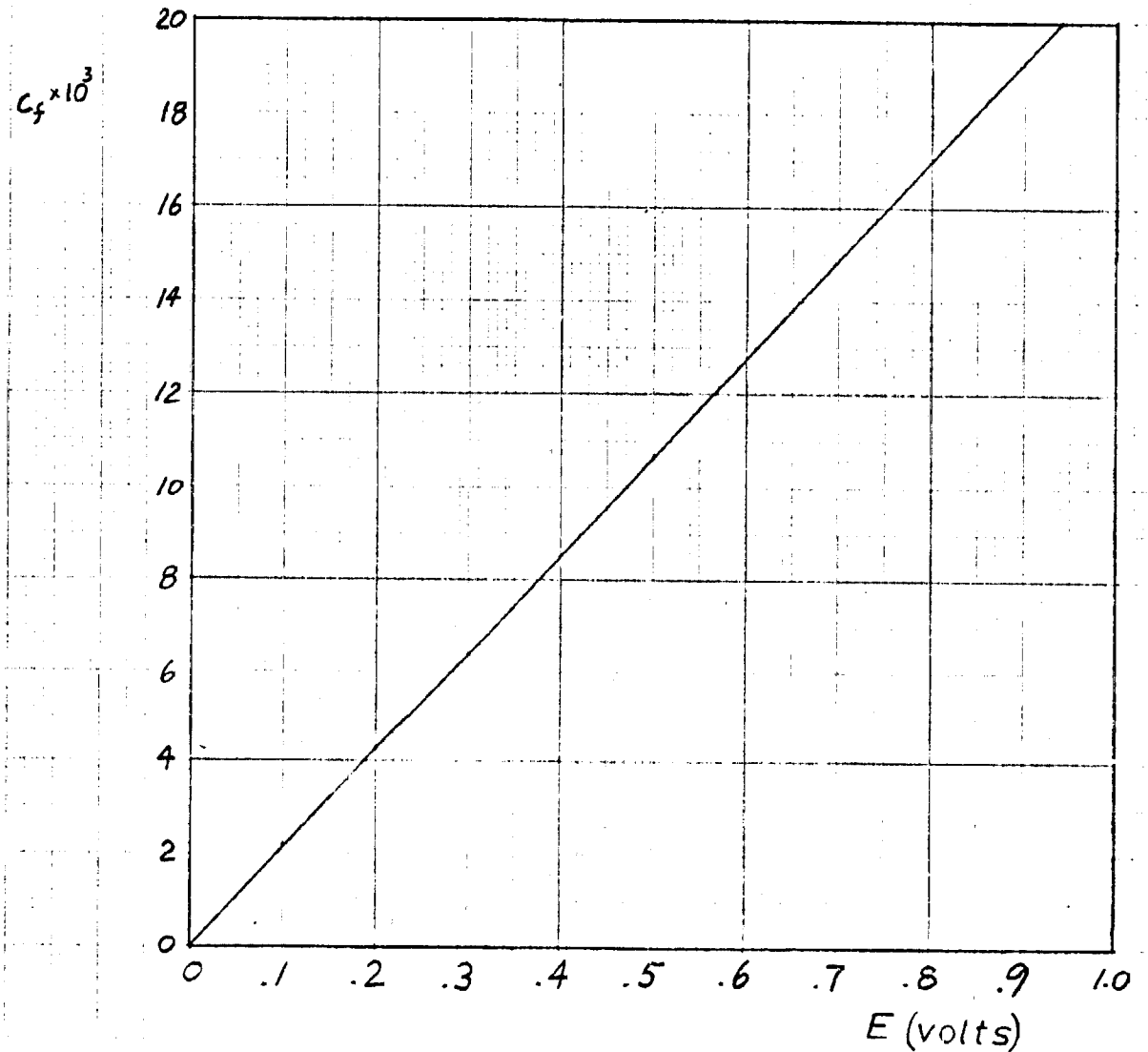

Fig. 7 CALIBRATION OF SKIN FRICTION GAUGE, range 10. gram/cm²

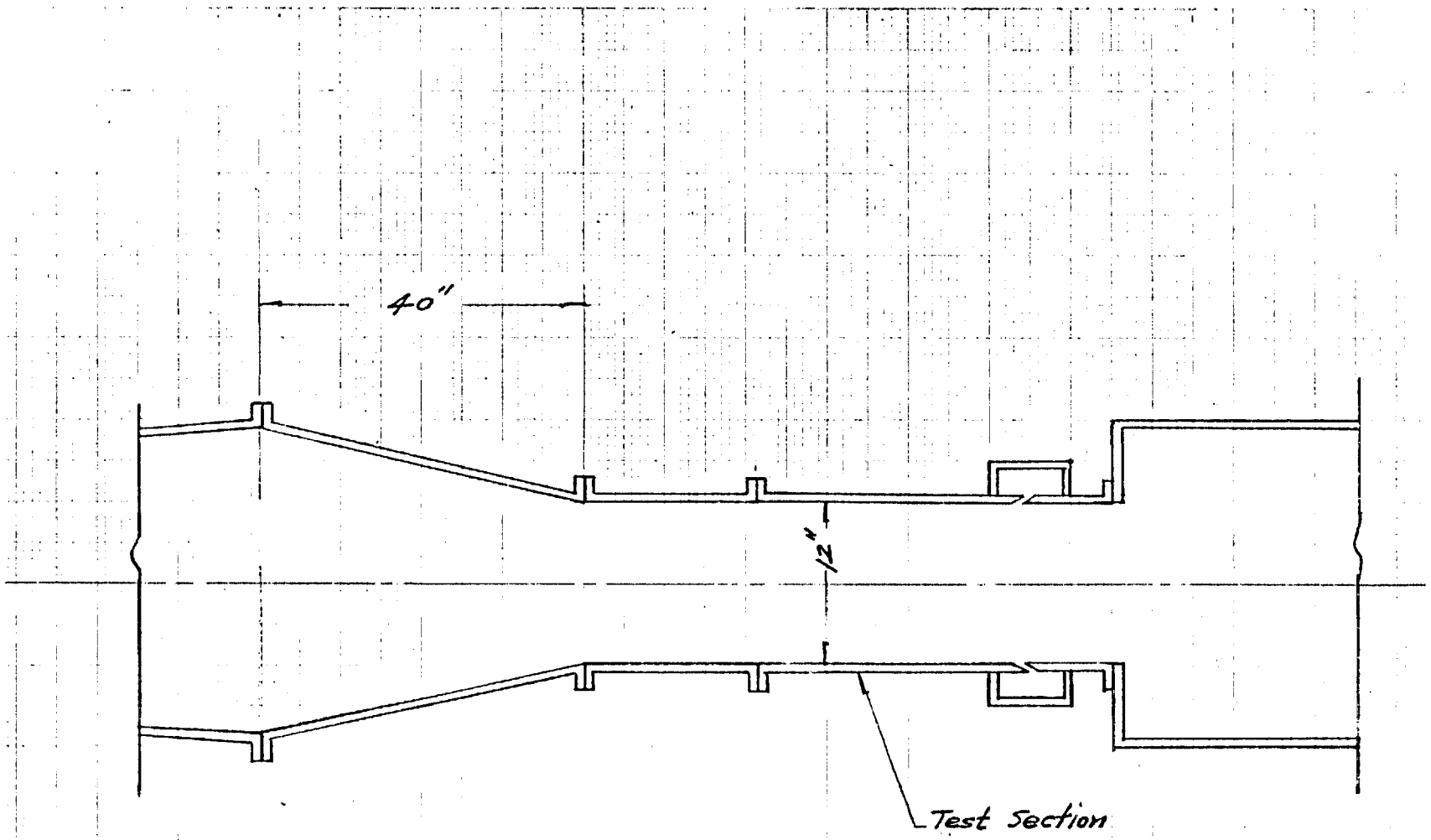

Fig. 8. Schematic of Wind Tunnel Setup for Tests without Upstream Injection Slot

λ_j	P_o (PSIA)	$\frac{U_j}{U_\infty}$
.05	114.54	.0468
.10	229.08	.0936
.15	343.62	.1404
.20	458.09	.1870
.25	572.69	.2340
.30	687.30	.2810
.35	800.00	.3270

Table 1: Calibration of Venturi Tube for 0.125 IN. Slot Height